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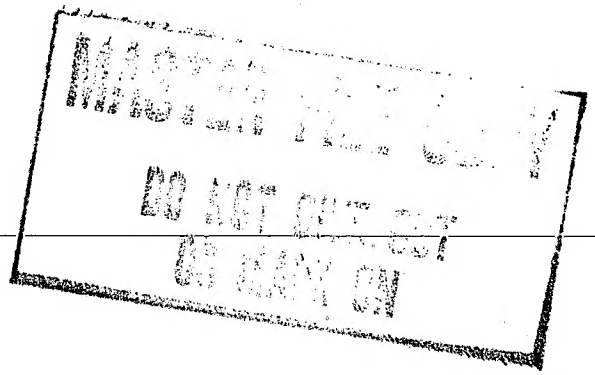

Soviet Optical Digital Computing—A Technology Alert

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An Intelligence Assessment

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Soviet Optical Digital Computing—A Technology Alert

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An Intelligence Assessment

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Soviet Optical Digital Computing—A Technology Alert

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Key Judgments

Information available as of 1 May 1985 was used in this report.

Soviet advances in optical digital computers (computers that use optical systems to perform numerical computations on data that are generally not images) could produce an important technological breakthrough between 1990 and 2000. The Soviets appear to be ahead of the United States in this area, and the implications of success could be dramatic. When fully developed, optical digital computers will be able to perform high-speed parallel processing calculations much faster and more efficiently than electronic digital computers.

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Some areas of computing such as sonar and radar signal processing, image analysis, and advanced robotic-vision applications, such as autonomous vehicles, currently burden electronic computers. These applications could be handled faster and more readily by optical computers. We expect the Soviet optical computing effort to be driven by the classes of military and scientific problems requiring high-speed calculations on large volumes of data. This class of problems is typified by aerodynamic and finite-element analysis problems and image processing where millions of picture elements must be quickly and repeatedly processed.

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The Soviet optical computer research program is organized, is being pursued at top institutes, and enjoys a high-degree of government support. No comparable level of effort exists in the United States. US research exists mostly at scattered academic centers.

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Dr. N. G. Basov, director of the P. N. Lebedev Physics Institute in Moscow, appears to be the center of leadership and activity of the Soviet effort. In 1984 Basov predicted that, before the turn of the century, optical digital computers capable of 10 billion operations per second will be designed. This rate is 10 times faster than the best speed predicted for the most advanced, US-made, electronic computers.

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We believe that, between 1987 and 1992, the Soviets probably will design an interim digital computer called a hybrid—a combination optical and electronic computer. The optical portion of this computer is expected to efficiently perform high-speed, high-throughput calculations that are inherently cumbersome for electronic computers.

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Optical digital computers under development in the USSR probably will not be based on the architecture and logic and command structures normally used for electronic computers. Basov has proposed a new logic concept, a variable operator, that uses an electrooptical component called a

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spatial light modulator (SLM)—essentially an electronically or optically controlled transparency—to perform arithmetic and logical operations. Electronic computers normally require many hardwired arithmetic and logical "subsystems" to perform functions similar to those provided by variable operators.

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Normally, Soviet research yields high-quality theoretical work with lesser quality hardware. In the optical-processing area, however, Soviet device development is of uncommonly high quality. In fact, one Soviet version of an SLM, one of the most essential devices needed for an optical computer, has been seen and examined by Western scientists and determined to be technologically at least five years ahead of comparable Western SLMs.

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Introduction

In the Soviet Union, research on optical digital computers is occurring at numerous research and development facilities. This paper focuses on the work done at the P. N. Lebedev Physics Institute in Moscow and by its director, Dr. N. G. Basov. The institute has, to a significant degree, been involved in the development of optical computing technology, and Basov appears to be leading the efforts in this field. From

articles by Soviet researchers (particularly Basov, whose statements we believe are important and accurate because of his position), we have been able to provide information on the direction and progress of Soviet optical digital computing.

Background

Information in a recent book,[1] jointly authored by an American, Herbert A. Elion, and a Soviet, V. N. Morozov of the Lebedev Physics Institute, has, when correlated with information from a 1978 Soviet journal,[2] given us important insight into Soviet progress in the development of optical digital computers. Basov wrote the introduction to the Soviet portion of this book. The 1978 journal articles were coauthored or at least endorsed by Basov.

For over seven years, Basov has been publicly critical of the capability and efficiency of electronic digital processors. His concern, to a large extent, is with limitations to the speed of both arithmetic and logical operations. In the introduction to the Elion-Morozov book, he explains that the relatively cumbersome method by which complex mathematical operations are carried out in normal electronic computers (by a series of basic arithmetic operations) supports his position about the efficiency of optical versus electronic digital computers.

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In the 1978 Soviet journal, Basov explained why electronic digital computers are inefficient devices for solving two- and three-dimensional problems important to many scientific and technical design and research questions. Although Basov acknowledged that special-purpose electronic digital computers are more efficient than general-purpose computers for multidimensional calculations, he also commented that they have limited utility and lack flexibility. In Basov's words, ". . . a very important shortcoming of such computers is the need to use essentially different machines for problems which are not that different." (This deficiency has changed since 1977; we now have programmable array processors, but their electronic mode of operation still limits performance.) Basov further states, ". . . these shortcomings can be largely avoided in an optical processor combining universality with a high efficiency of data processing." He concluded that the primary advantage of optical over electronic processing is ". . . the ability to process data in parallel on a large scale."

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In this report, we emphasize the Lebedev work under Basov because it is the most comprehensive Soviet research effort. In addition to the Lebedev Institute, there are other institutions conducting research on optical processing (see table). Important optical computing components (such as the PRIZ device, discussed later in this paper) are fabricated at the Ioffe Institute in Leningrad under M. Petrov. The Leningrad Nuclear Physics Institute at Gatchina has a large online optical memory system with many terminal accesses that has been operational for several years.

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[1] Herbert A. Elion and V. N. Morozov, Optoelectronic Switching Systems in Telecommunications and Computers, Marcel Dekker Inc., New York, New York and Basel, Switzerland, 1984.

[2] N. G. Basov et al., "Principles of Design of Optical Processing With Variable Operators," Soviet J. Quantum Electronics 8 (3), March 1978 (paper submitted for publication March 1977).

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Discard the Old Approach

In his introduction to the Elion-Morozov book, Basov wrote that progress in future computer engineering will be handicapped if one uses old hardware for future computers or repeats old structures with new hardware. Basov states the generally known fact that electronic computers cannot continue to advance in operating speed because of limited signal speed in interconnections. He states, "the speed of electronic arithmetic and logic devices grows essentially slower than that of the elements (elements refer to switching circuits, transistors, and gates) and is about t to the 0.6 power, where t is element speed." He also relates interconnection length to the number of gates in an integrated circuit and their effect on computer speed. Expanding further, he explains how these electronic device limitations suggest that new approaches to computation require the development of "new hardware." By "new hardware" he means optical devices and systems that use light instead of electrons as information carriers.

Western optical analog computers have been specialized and lacked flexibility. In the United States, when optical computers are discussed, they are often thought of as analog computers that are based on Fourier transforms and used in frequency analyzer, correlator or other transform applications. Recent US research on optical matrix-vector processors promises general-purpose systems, but no significant US effort exists in this area.

The relative lack of Western interest in optical computing could be a consequence of our clear success in electronic computing technology. Western electronic computer technology has matured quickly, given us remarkable computational capability, and still has room to grow. Until now, we could see more immediate payoffs from improving mature electronic technologies, rather than venturing into the longer leadtime

Table
Soviet Institutes Involved in Optical Computing and Their Apparent Key Efforts Related to Optical Processing

Institutes	Optical Programs
Primary Centers	
Lebedev Physics Institute,[a] Moscow	Program to develop an optical computer.
A. F. Ioffe Physicotechnical Institute,[a] Leningrad	Optical computing components. Device (PROM, PRIZ, etc.) technology on par with or exceeds US technology (depending on device).
Institute of Automation and Electrometry (IAE),[a] Novosibirsk	Holography. Matrix multipliers.
Institute of Radio Engineering and Electronics, Moscow	High-bandwidth signal-processing correlators. Military funding received (no further details).
Secondary Centers	
Cybernetic Center, Kiev	Conventional electronic computer design and prototyping (produces its own microcircuits). Holograms. Integrated optics. Cryogenic computing.
Labor Institute of Physics, Gorkiy	Lasers. Acoustooptic crystals.
Institute of Information Transmission Problems, Moscow	Holography using incoherent light.
Leningrad Institute of Precision Mechanics and Optics, Leningrad	Little significant intelligence information available. Textbook on optical information processing including design limits.
S. I. Vavilov State Optical Institute, Leningrad	Optical sensors. Optical system applications. Classified (unknown) work. Military applications of holography.
Leningrad Nuclear Physics Institute, Gatchina	Large volume holographic memories with electronic terminal access.
Belorussian Physics Institute	Optical logic elements. Thin film lasers.

[a] Work at Lebedev, Ioffe, and IAE—the top three institutes doing optical computing research and development in the USSR—overlaps. These three laboratories are also competitors.

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efforts needed for developing optical computers. We cannot document reasons why the West has not developed optical computing systems more vigorously; we simply note the Western interest and success in electronic computing and our lesser interest in longer term optical computing projects.

On the basis of Basov's statement about using new devices in old architectures, we conclude that using optical devices that are analogous to electronic logic devices in existing electronic computer architectures will only provide incremental improvements in speed. Other architecture, logic, and "hardware" suggested in Basov's papers probably can provide an order of magnitude gain in computational speed over the best predicted future electronic computer capabilities.

Optical processors using coherent radiation from lasers can provide the capability for two-dimensional calculations in less than the time for one clock pulse. For example, an n by n element matrix can be projected in two dimensions onto a spatial light modulator (SLM) and can be multiplied by n component vectors in one operating cycle. The ability to project all elements of the matrix onto an SLM as a "picture" and then operate on all elements simultaneously is what we mean by parallel processing. (SLMs are discussed later in this paper.) The coherent, short-wavelength laser radiation used as the "carrier"—from a spatial information viewpoint—permits the two-dimensional computational capability. Holographic materials will be able to provide a three-dimensional (two spatial dimensions plus phase information) storage capability. Most experiments today, however, use holograms for two-dimensional storage. The coherent radiation source most often used is a laser that operates in the visible portion of the spectrum, where the wavelength is less than 1 micrometer.

Critical Optical Devices

Two critical device technologies are associated with digital optical computers: real-time spatial light modulators (SLMs) and reusable holographic memories. SLMs are used to enter data into the computer and to perform logic and arithmetic functions. Holographic memories provide parallel storage of data and, in the Soviet variable operator concept, also store computer commands. 25X1

Spatial Light Modulators

SLMs are essentially electrically or optically controlled transparencies or reflecting surfaces.[3] Two-dimensional picture information can be projected onto, and read, from these flat surfaces. Images in digital picture form, representing instructions, can be projected (using a laser, for example) onto one side of a flat SLM. Input variables—again in digital picture form—can be projected onto the other side of the SLM. Using superposition of the control operator and the input variables, data processing or transformation can occur. The optical properties of the SLM are modulated by the control operator and the input variable picture. Depending on SLM design, the reflected or transmitted, modulated output light contains the results of the operation. 25X1 25X1

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the Soviets are probably at least five years ahead of the United States in research and fabrication of SLMs. One type of SLM, called a PROM (Pockels Readout Optical Modulator), was invented by the Itek Corporation, a US firm, in about 1972. US work on PROMs and research on electrooptic materials was almost dormant during the rest of the 1970s. 25X1 25X1

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In the 1978 journal, Basov discussed a PROM device that he claimed had a sensitivity of 5 microjoules per square centimeter and could resolve 100 lines/mm. In

[3] SLMs are made from materials in which the index of refraction varies with the optical intensity of incident light. 25X1

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the same journal, the Lebedev group said that these characteristics were adequate for processing both digital and analog data, but it believed the frame rate would be limited to 1 kHz. This sensitivity given in 1978 is the same as 1982 and 1983 data on Soviet PRIZ SLMs and a factor of 100 better than any known Soviet or US PROM of that period. The resolution given in the 1978 data is about 50 percent better than the 1982 PRIZ data. We believe the PROM described by Basov in the 1978 journal was in reality a PRIZ (a crystallographically modified PROM), which apparently could have existed as early as 1976 in the Soviet Union. If so, the Soviets may lead the West in PRIZ technology and production by more than the five years estimated.

Another possible type of SLM is the latrix. In 1978 the Lebedev scientists found fault with the PROM because of its slow 1-kHz maximum cycle rate and because it required a laser of one wavelength to "write" data and a laser of a second wavelength to "read" data from the PROM. They were not satisfied with their PROM device even though they said it had some operational utility. In addressing the problem of digital SLMs, they discussed the latrix. The Soviets praised the latrix's virtues, especially its sensitivity to light pulses, which they said should be better than 10 to the 12th joules/element. It therefore appears that the latrix could be much more sensitive than the PRIZ.

The latrix was originally investigated at RCA Laboratories in Princeton, New Jersey, before 1970. Two RCA scientists described the latrix in a 1970 US optical journal as an integrated array of photosensors, light valves, and a transistor memory. The light valve used in the latrix was a liquid crystal, which can also be used as an SLM. The fate of the latrix as a digital SLM for optical computers is not known, but it was mentioned in Morozov's section of the jointly authored book; articles on the latrix have rarely appeared in recent US journals.

Another group of researchers concurred with and added to the SLM studies done by the Lebedev group. In a 1983 article, authors from the IAE in Novosibirsk described the PRIZ SLM in the same sensitivity terms—namely 5 microjoules per square centimeter—that previously had been reported by other Soviet authors. These Novosibirsk researchers also stated, however, that the sensitivity of SLMs needs to be 0.1 to 0.001 microjoules per square centimeter for use in processors. The Novosibirsk researchers then said that they developed an enhanced PRIZ with a sensitivity of 0.08 microjoules per square centimeter, nearly 100 times more sensitive than its predecessor. Its sensitivity was enhanced by doping the BSO crystal with tin through a diffusion process. The resolution of the enhanced PRIZ was 50 lines/mm and its dynamic range was 51dB; both specifications are within Novosibirsk's specification for SLMs that are useful for processors. On the basis of our information on the PRIZ, we assess that the Soviets have at least a limited capability to produce SLMs—most likely the enhanced PRIZ—for both digital and analog optical processors. 25X1 25X1

Memories

We believe, when evaluating Soviet progress in optical computers, it is important to note that in the 1978 journal Basov and his colleagues wrote that the practical realization of optical processors was difficult mainly because of the lack of suitable devices. Basov stated that a serious (1978) difficulty was the lack of a reusable holographic memory that would satisfy sensitivity and high-spatial resolution requirements. In the 1978 journal, he further wrote that the materials available for optical memories included photochromic and chalcogenide glasses and doped ferroelectric crystals and that a considerable increase in the sensitivity of (memory) materials could not be expected in the near future. It thus appears—at least in unclassified discussions—that sensitive holographic materials were not available to Basov's group in 1977. 25X1 25X1

Basov and his associates also wrote that parallel optical memories were "already" available to deal with 1,000 to 10,000 bits at the same time. We know 25X1

that by 1983 the Soviets had improved optical memories that could store 10,000 megabits of information. 25X1

The Elion-Morozov text states, "that a 1 mm by 1 mm hologram accommodates 1,000 to 10,000 bits, and that a 5 cm by 5 cm plate accommodates 1,000 holograms." This structure is apparently referred to

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by the Soviets as a hologram matrix. The Soviet authors also state in the 1984 book, "It is expedient to implement memory . . . by holographic memories *that are sufficiently evolved.*" This information indicates that in a six-year period the Lebedev workers probably increased optical memory capacity by a factor of one million. The 1983 memory capacity is almost certainly adequate for use as a buffer memory in digital optical computers. The Soviets seem to have solved their holographic memory problems sufficiently to continue developing optical computers. The important point about holographic memory from an optical computing perspective is not the amount of data stored, but that holographic memories can have parallel data readout, rather than serial readout as usually occurs with electronic memories. An optical computer capable of parallel operations would be of much less value if data needed for computations had to be read in and out serially.

Departure From Conventional Arithmetic and Logic Operations

Lebedev's 1978 journal included analysis and descriptions of the type of elements that would allow logic and arithmetic functions, which are important because they allow optical computers to be programmable and reconfigurable for a variety of applications. Programmability is a departure from the conventional present day thinking that optical computers are generally specialized, inflexible machines that perform "prewired" functions that are difficult-to-impossible to change. In the following discussion, we consider (at least) [4] two-dimensional logic and arithmetic operations that cannot be efficiently implemented in electronic computers.

The Lebedev workers have proposed a new logic concept called variable operators, which are function generators stored in an optical holographic memory. Function generators do not exist in an explicit unit of hardware at any given time; they are essentially an instruction set that can be projected onto an SLM transiently as required by the data-processing algorithm. Figures 1 and 2 illustrate the variable operator concept. 25X1

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Soviet optical computing with variable operators will provide a wider range of "hardwired" functions than a traditional digital electronic processor. The instruction set can be changed at will by projecting a new control hologram. In addition, the variable operator computer can be used as an adaptive processor, with its adaptive properties appearing at the lowest (logic) level. Figure 3 shows a representative arrangement of optical computing components as they might appear in an optical computer. 25X1 25X1

From Basov's 1984 information, we found that the Lebedev researchers have continued work in the field of variable operators. Basov wrote that the concept of variable operators is a promising "idea," but his statement leaves us with unanswered questions about Soviet progress in implementing variable operators over the past seven years. The Elion-Morozov book gives an extensive discussion of control operators in optoelectronic processors—from design philosophy to specific examples. Vector-matrix calculations such as a fast search for a minimal number in a binary array (important in process optimization and control) are discussed, and the text shows the optical diagram of the computing units needed for the operation. Given the extent and detail of the published Soviet work, we believe the Soviets are making progress on variable control operators for optoelectronic digital processors. In the past, work on variable operators could have been inhibited by the lack of suitable technical devices such as SLMs. Basov's prediction of results "before the turn of the century" and the fact that the Soviets are working on all aspects of the optical computing 25X1

[4] Optical computers do not have to have planar circuits as is the case with electronic circuitry. Optical computers can have data flow in three dimensions, which implies massively parallel architectures with extremely high throughput capacities.

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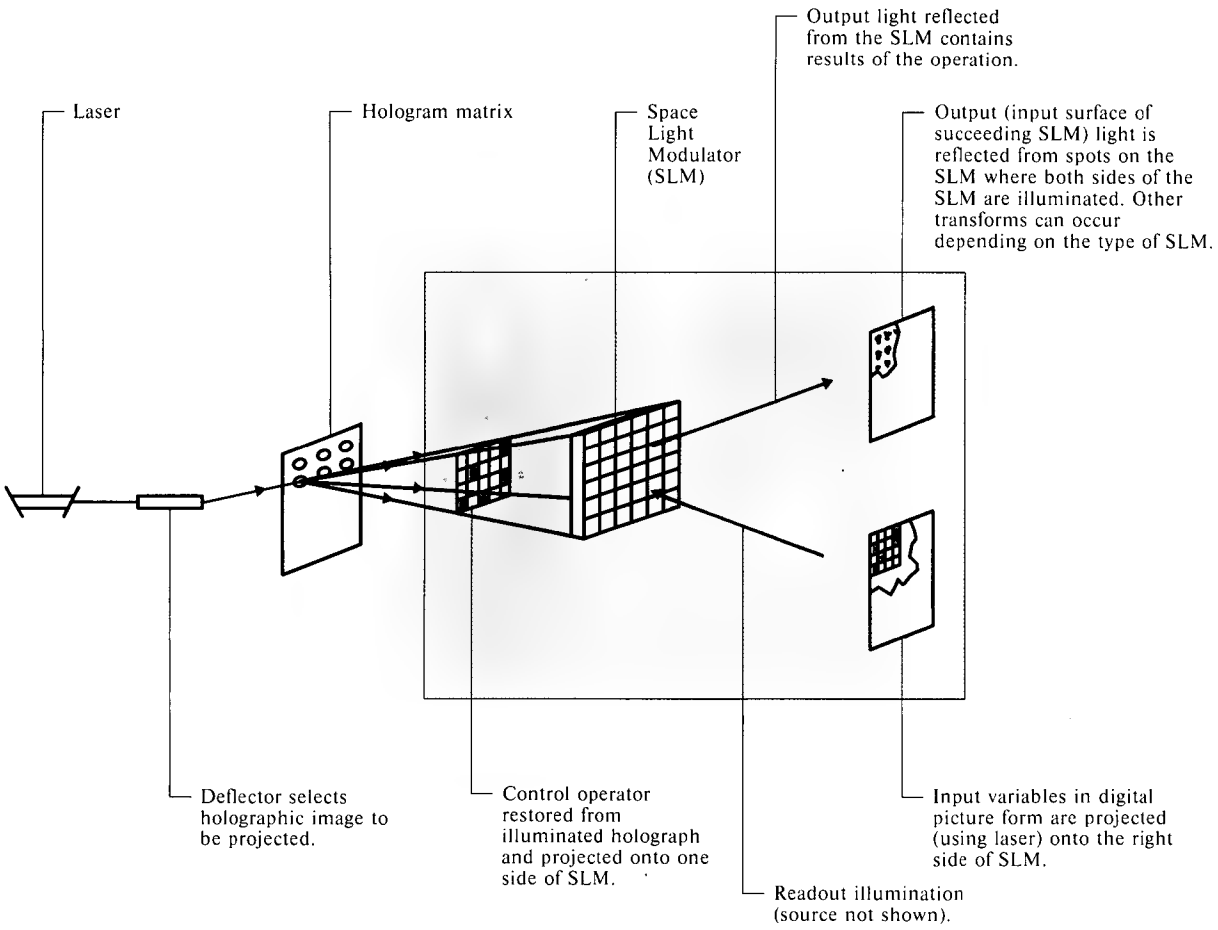
Figure 1
Control Operators in Optical Computers



How Data Processing Occurs

The laser and deflector illuminate the selected hologram to project a control operator picture onto one side of the SLM. Input variables in digital picture form are projected onto the other side of the SLM. Using superposition of the control operator on one side of the SLM and the input variables on the other side of the SLM, data processing occurs. The optical properties of the SLM are modulated by the control operator and input variable picture. The modulated, reflected output light contains the results of the operation. This light falls on the output SLM.

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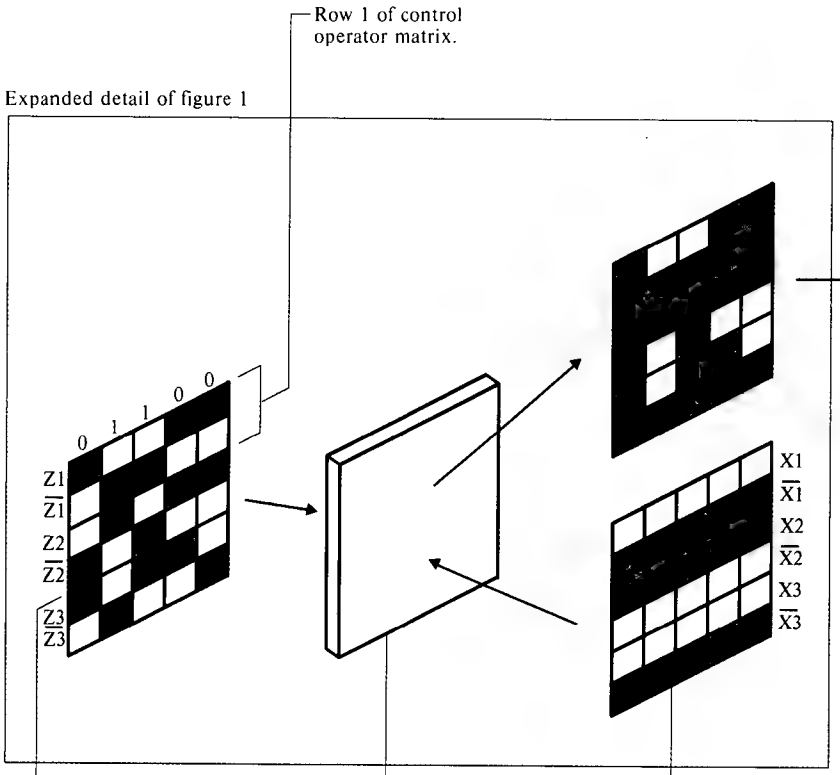
Figure 2
Example Showing an Input Variable Transformed by a Control Operator



$$\{Z_{ij}\} = \begin{bmatrix} 0 & 1 & 1 & 0 & 0 \\ 1 & 0 & 1 & 0 & 0 \\ 0 & 1 & 0 & 0 & 1 \end{bmatrix}$$

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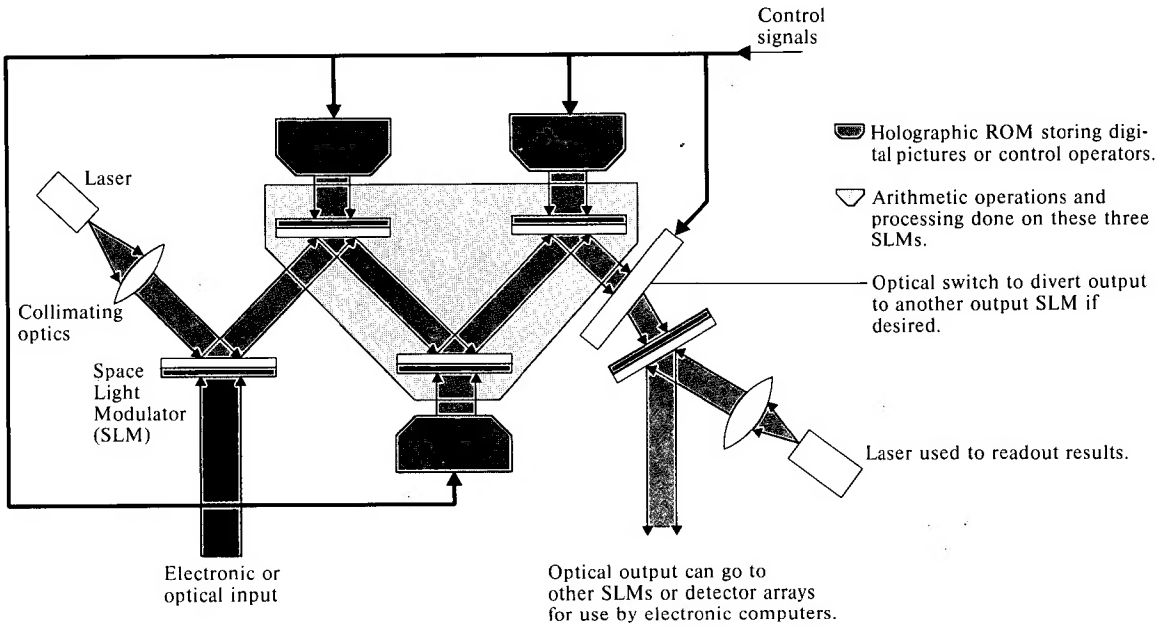
Figure 3
Representative Optical Data Processing Path



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problem allow us to reasonably predict success in their variable operator research soon enough to avoid limiting their general optical computing effort.

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Expectations

The concluding sentence in the introduction to the Elion-Morozov book gives us a sense of Basov's expectations and perhaps the Lebedev Institute's progress: "It seems quite probable that optoelectronic processors with a speed of 10 to the 10th operations per second will be designed before the turn of the century."

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The Soviets' seemingly thorough approach to optical computing (from architectural considerations to hardware design), their strong research program, and clearly observed technical successes (Soviet SLMs seen in the West and reporting on other optical storage systems) lead us to conclude that Basov's prophecy about high throughput general-purpose optical computers will probably come true. We expect the effort to be driven by the classes of military and scientific problems requiring multidimensional calculations. Work on digital optical computers is presently

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being carried out at the Lebedev Institute and at least 10 other Soviet institutes. We should not be surprised by the appearance of a Soviet programmable, digital optical computer during 1990-2000. We were surprised in 1981 when a critical component of these systems, the PRIZ, was disclosed.

We anticipate that an interim computer, based on both electronics and light, probably could be ready for use between 1987 and 1992. These computers, called hybrids, would be capable of performing matrix calculations more efficiently than electronic digital machines. Applications such as synthetic aperture radar data processing, acoustic array processing, and image processing are some important applications that would benefit from the use of a hybrid computer.

Potential Optical Digital Computer Applications

Optical digital computers will be most useful in solving high-throughput-demanding two- and three-dimensional aerodynamic and finite-element analysis problems, signal-processing problems, and image analysis problems. Most computers today operate serially (they perform operations one at a time). More advanced parallel electronic computers perform several operations simultaneously and are much faster. They are also more complex and expensive than serial ones. US work on digital systolic and similar multiprocessor architectures promises high computation rates, but these systems are generally special-purpose arrays of processors not easily reconfigurable for new operations. The general-purpose optical digital computer ideas being considered in the USSR are fundamentally new concepts: new architectures and new physical components; they will also require new partitioning of problems to take advantage of the inherent parallelism in optical computer designs.

Image Processing

Image processing is expected to be improved by using optical digital computers. Real-time image processing has well-known and important tactical and strategic military value. Earth resources imagery applications that have economic significance can also be improved but not as dramatically as military applications. Processing imagery data on computers is costly and time consuming because of the millions of picture elements (pixels) of data that must be repeatedly processed. High-throughput (faster) optical computers are expected to make these imagery processing functions more tractable

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One image-processing function that is particularly important in military applications is image enhancement, presently performed "off line" with electronic digital processors. Enhancement improves the outline or edges of images that have been degraded by atmospheric effects or by sensor platform vibration. Another important military image processing task is that of being able to simultaneously find and mark all targets such as tanks, aircraft, or ships on a video display. This function, called two-dimensional correlation, can theoretically be more efficiently implemented on an optical processor.

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Synthetic Aperture Radar Signal Processing

Optical digital computers should prove to be of value in improving the spatial resolution and timeliness of Synthetic Aperture Radar (SAR) imagery data because of their potentially high throughput. SARs take advantage of the forward motion of an airborne or spaceborne radar to produce the equivalent of an array antenna kilometers long (aircraft case) or tens of kilometers long for spaceborne systems. They produce radar maps that look like imagery taken with a vertically oriented airborne camera. The amount of signal processing required is a major constraint on the fineness of resolution or the size of an area (for a set resolution) covered. The SEASAT radar, for example, was a US spaceborne radar that orbited the earth at an 800-kilometer altitude. It mapped 125 million square kilometers and used a 25-by-25-meter cell size, bringing the number of cells to be processed to around 200 billion. Had the cell size been reduced to 3 by 3 meters as would have been necessary to resolve vehicles and houses, the amount of processing would have increased by roughly 64 times. The SEASAT SAR was designed to relay its data to earth for ground-based computer processing. The large amount of information the radar gathered could be reasonably analyzed and interpreted over a period of months and years. If a radar like SEASAT were used for military

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missions with real-time processing, the computer processing requirements would be staggering. For example, real-time processing of SEASAT-type imagery employed for ocean surveillance would require a computation speed of at least a billion operations per second. Onboard electronic computers of this speed and capacity do not now exist. Optical computers of the kind discussed by the Soviets would allow this kind of processing.

Sonar and Seismic Array Processing

The Soviets have already used analog optical processors on seismic information. Optical digital processors should allow real-time operation with improved accuracy in sensing amplitude, range, and direction of a seismic process. Seismic sources can include earthquakes or tremors from explosions. Both seismic sensor arrays and underwater acoustic arrays can be arranged in the form of a matrix to provide data that can be efficiently processed by an optical digital computer. The relatively narrow bandwidth (information rate) requirements (which reduce processing requirements) of seismic sensors suggests that very large matrices of sensors could be deployed and operate with real-time data analysis.

Reliable real-time processing of acoustic antisubmarine warfare (ASW) sensor array information is critical. Again, the bandwidth of underwater acoustic sensor information is relatively low, and thus, optical processors could allow use of large arrays or make interarray processing feasible—with consequent improvements in sensing range and locational accuracy. For large ASW arrays, interarray processing is the function most limited by computer processing capability. Each array receives signals sorted in direction and frequency that must be correlated with similar signals from other arrays. This interarray processing needs to be able to create and process thousands of ambiguity functions each second. Such applications would require computer throughput rates of the order of billions of operations per second for real-time processing.

Flow Problems

Flow problems cited by Basov in the 1978 Soviet journal dealt with the problems of solving a three-dimensional gas dynamic problem. This problem is related to a wide variety of aerodynamic and ballistic problems of important technical and military significance, such as gas dynamic lasers, propulsion systems or meteorological problems. The three-dimensional nature of gas-dynamic problems and other modern flow problems, together with the number of variables involved, makes the solution of this class of problem difficult-to-impossible on electronic computers. As an example, a sustained processing speed of about a billion operations per second is needed to simulate three-dimensional airflow about an aircraft. For comparison, three-dimensional flows about simple objects still require impractically long-run times of up to 20 hours on current supercomputers. These long-run times allow a few solutions to be run; a faster system would allow a large number of computer runs to occur. Fast, quickly repeated computer runs are needed to optimize designs. This type of design tool does not exist for this class of problems. 25X1

Multisensor Defense Problems

The use of a multisensor system to warn of, localize, and evaluate a threat against the USSR represents a severe data-processing problem. By a multisensor system, we mean spaceborne sensors that could include infrared (IR) launch detection, high-resolution visible-spectrum imaging sensors, long-wavelength IR imaging sensors, spaceborne and ground-based phased array radars, and any of a number of potential acoustic and nonacoustic ASW sensors. The amount of data and the data rate from such a defensive sensing system, even after a considerable amount of preprocessing, is staggering. One function that would certainly be applied to these data is correlation of multisensor information, such as spaceborne radar tracking information, target cross section and velocity with IR track data that might originate from a satellite, or track data from other sensors such as over-the-horizon radars or airborne radars. In this application, speed of processing by an optical computer is an important attribute because timely and critical defense decisions must be made. 25X1

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